In-Use Emissions by Vehicle Model

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Previous research indicates that there is a wide range in in-use emissions by vehicle model. Data on average emissions by vehicle model can be used for a variety of purposes, from identifying suspected low-emitting vehicles for exemption from I/M testing, to creating incentives for consumers to purchase, and manufacturers to build, vehicles with durable emissions controls. Last year we demonstrated the consistency in failure rate and average emissions by model year and model, using three years of data from the Arizona I/M program. We also presented a preliminary comparison of average emissions by vehicle model from several IM240 programs. This year we more thoroughly compare average emissions by vehicle model from the Arizona, Colorado, and Wisconsin enhanced I/M programs.

Elements of Three I/M Programs

Table 1 summarizes the key features of the enhanced I/M programs in Arizona, Colorado, and Wisconsin. Important differences are the cutpoints used (Arizona's and Wisconsin's are similar, while Colorado's tend to be less stringent), and the model years tested in each year (while Arizona tests all model years each year, Colorado tested mostly odd model years in 1997 and Wisconsin tested mostly even model years). Differences in the test cycles in Colorado and Wisconsin complicate analysis between the two programs. **Figure 1** demonstrates the difference in test cycles in the Colorado and Wisconsin programs. The figure shows the number of vehicles tested from July to December 1996 in all three states, by model year.

Similar numbers of vehicles from each model year were tested in Arizona in 1996, while the majority (90%) of vehicles tested in Wisconsin are from odd model years, and most (65%) of the vehicles tested in Colorado are from even model years. Colorado requires an I/M test when a vehicle is sold, and the next scheduled I/M test is not required until two years later. Therefore, most of the large number of vehicles from odd model years tested in 1996 were sold at some point earlier in their lifetime. (In contrast, vehicles sold in Wisconsin do not change their test cycle; the small number of even model year vehicles tested in 1996 in Wisconsin are early or voluntary tests.) In order to get large enough samples of vehicles from a particular model year in each state, we use 6 months of data from two calendar years, July 1996 to June 1997. **Figure 2** shows that this approach reduces the "sawtooth" effect due to different test cycles in Colorado and Wisconsin.

Figure 1. Number of Vehicles by Model Year and State

Passenger Cars, July 1996 to December 1996

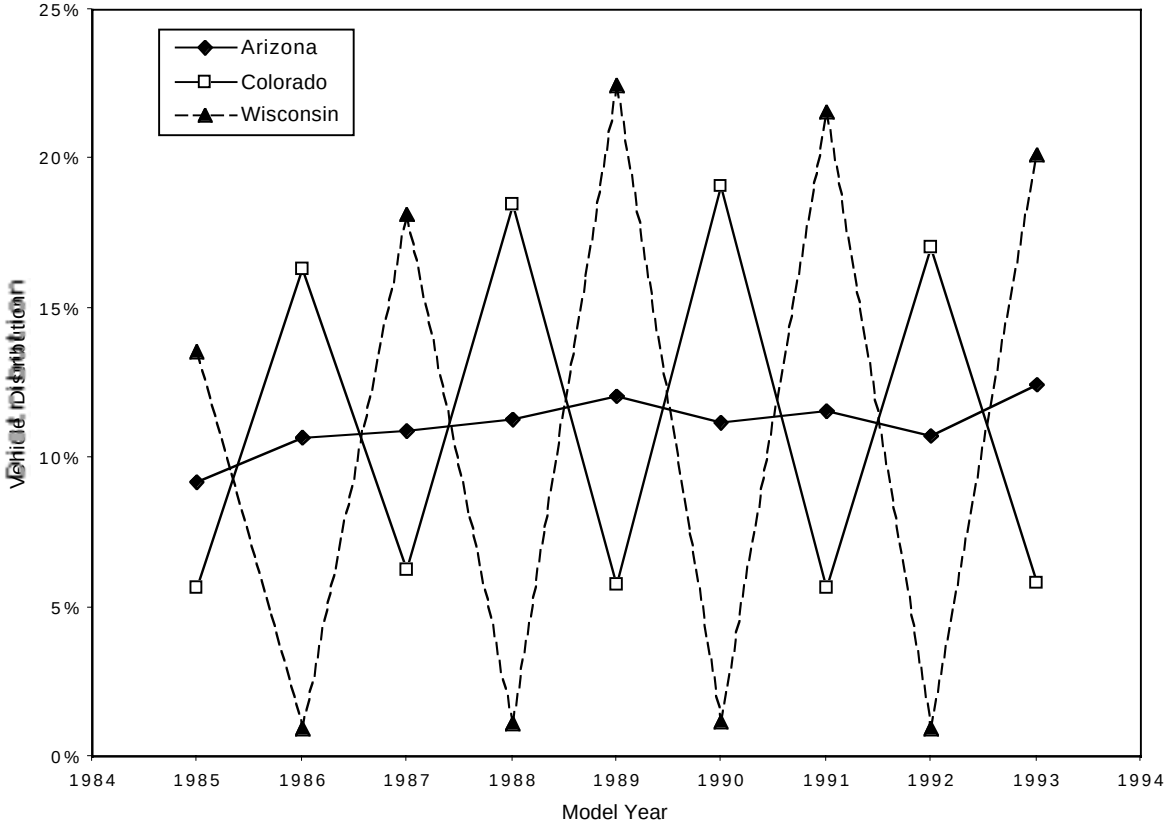


Figure 2. Number of Vehicles by Model Year and State

Passenger Cars, July 1996 to December 1996

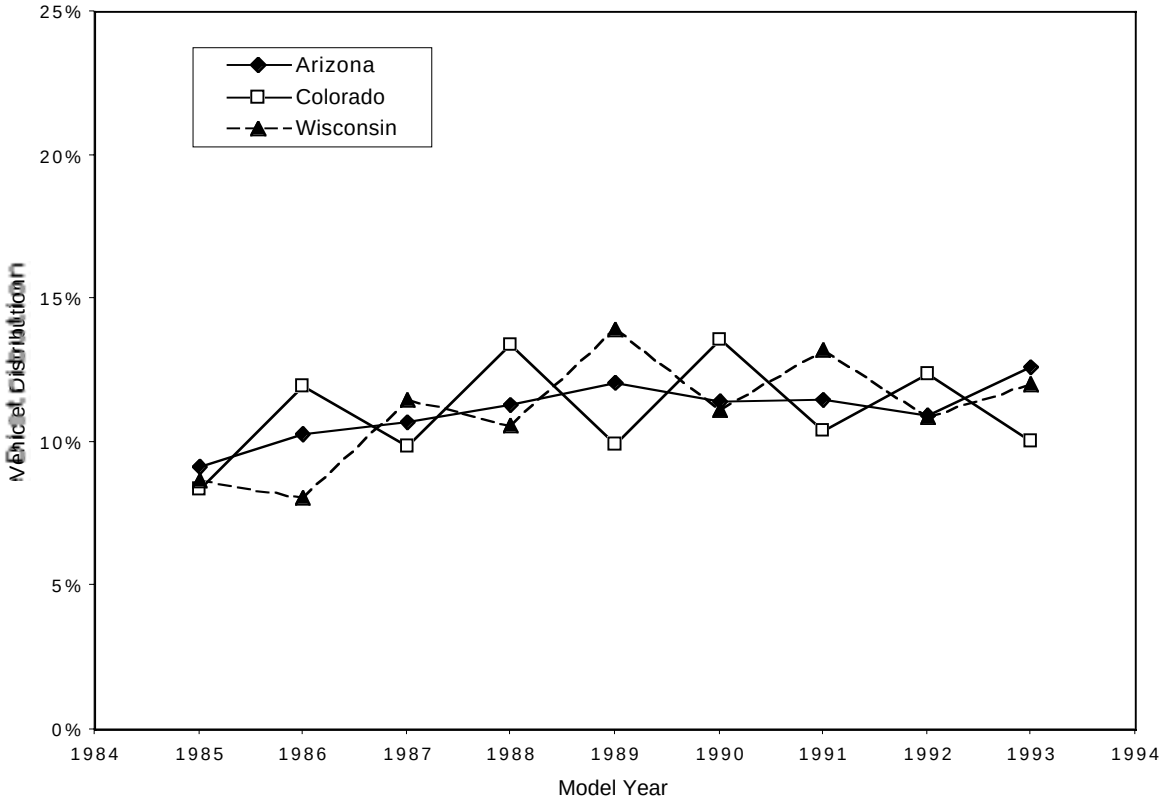


Table 1. IM240 Program Elements in Three States

Program Element	Arizona	Colorado	Wisconsin (1)
Test Cycle	biennial; all MYs tested in 1997	biennial; odd MYs tested in 1997	biennial; even MYs tested in 1997
Test on Resale?	no	yes	yes
Composite Cutpoints (cars)			
HC	91-95: 1.2 81-90: 2.0	86-95: 4.0 82-85: 5.0	91-95: 1.25 81-90: 2.0
CO	91-95: 20 83-90: 30 81-82: 60	91-95: 20 85-90: 25 83-84: 50 82: 65	91-95: 20 83-90: 30 81-82: 60
NOx	91-95: 2.5 81-90: 3.0	95: 4.0 86-94: 6.0 82-85: 8.0	*91-95: 2.5* *81-90: 3.0*
Fast Pass?	yes	yes	yes
Fast Fail?	yes	no	no
Phase 2 Pass?	yes	no	yes
Second Chance to Pass?	no	yes if emissions <2x cutpoint	yes if emissions <2x cutpoint
Full Tests	random 2%	all vehicles tested 1/97 to 3/97	1996: all vehicles tested on weekends; 1997: random 2%

(1) Cutpoints shown were effective 12/96 to 11/97. Although Wisconsin tests for NOx, vehicles are not failed for exceeding NOx cutpoints. Vehicles tested during weekends in 1996 were given full test; this practice was replaced by 2% random sampling in 1997.

Adjusting Short Test Emissions to Full IM240 Equivalents

In our analysis we use average emissions rather than failure rate, since the emissions cutpoints differ among the states and many new car models have low failure rates. Within a state, average emissions by model correlate quite well with failure rate by model. A limitation of using average emissions is that IM240 testing procedures are not consistent between vehicles. All three states allow the cleanest vehicles to pass after 30 seconds of testing (fast passes); Arizona allows the dirtiest vehicles to fail after 94 seconds (fast fails), while Colorado and Wisconsin give all failing vehicles the full IM240 test.

To compare emissions from vehicles tested over different portions of the IM240, we need to correct fast-pass/fast-fail emissions to full test equivalent values. We use the same simple methodology to convert short test results in Arizona and Wisconsin to full test equivalent emissions. This methodology uses correction factors based on the average ratio of emissions at each second to full test emissions, for each pollutant and second of the IM240. Colorado uses a slightly different methodology to convert short test emissions to full IM240 equivalents; we use the Colorado adjustments for the vehicles tested in the Colorado program. For our purposes here, we do not require that this correction results in absolute accuracy for individual vehicles; rather we look for consistent ranking of models among the three states.

Arizona runs full IM240 tests on a random sample of two percent of the vehicles in the fleet; in Colorado, the fast-pass feature was "turned off" for all vehicles tested in the first three months of 1997 (that is, all vehicles tested during this period received a full IM240 test). We compare the average CO emissions of full tests with those of fast-pass/fast-fail tests, by vehicle model, in Arizona (Figure 3) and Colorado (Figure 4). The model year 1990 to 1993 car models shown have full tests on at least 10, and fast-pass/fast-fail tests on at least 250, individual vehicles.

Figure 3 indicates that there is no consistent bias in our adjustment procedure; average adjusted emissions by model from fast-pass/fast-fail tests in Arizona match very well with average emissions from full IM240s (perfect correlation between full tests and fast-pass/fast-fail tests is shown as a solid line, the actual correlation is shown as a dashed line). CO emissions from both fast-pass/fast-fail and full IM240 tests are higher in Colorado than in Arizona. As shown in **Figure 4**, the procedure to adjust Colorado fast-pass emissions appears to be somewhat biased. The Colorado procedure slightly overpredicts adjusted emissions from low emitting models, and slightly underpredicts adjusted emissions from the high emitting models. This is surprising, since the emissions from the highest-emitting vehicles, which have the biggest influence on average emissions of a particular model, are not adjusted, because all failing vehicles receive the full IM240 test in Colorado. Figures 3 and 4 indicate that the two different procedures used to adjust short test emissions to full IM240 equivalents give qualitatively similar results.

Figures 3 and 4 also show the value of using the average emissions values for vehicles receiving the short test. The vertical "whiskers" are the standard error associated with the full test cars, while the horizontal whiskers are the error of the fast-pass/fast-fail cars. The figures graphically demonstrate how an increase in the number of individual vehicles tested greatly reduces the statistical uncertainty of the average emissions of that model.

Figure 3. Average CO by Model, Fast Pass/Fail vs. Full Tests

Arizona MY90-93 with over 10 full IM240 tests (July 1996 -- June 1997)

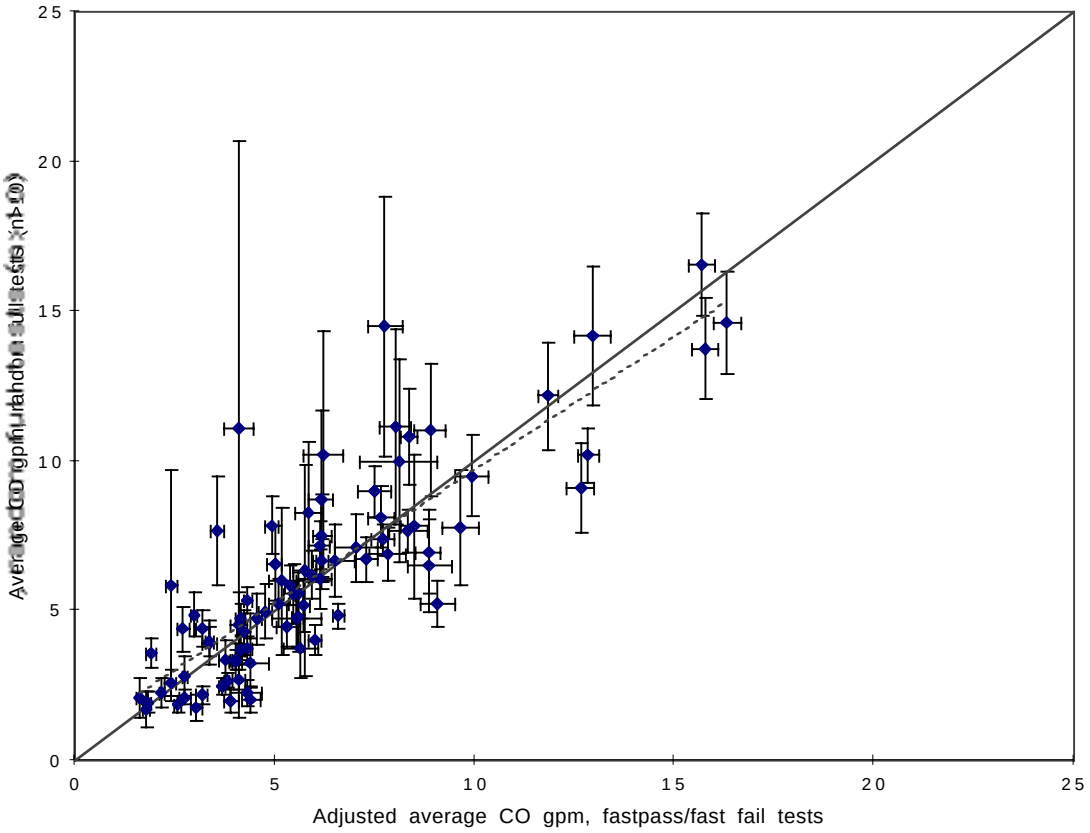
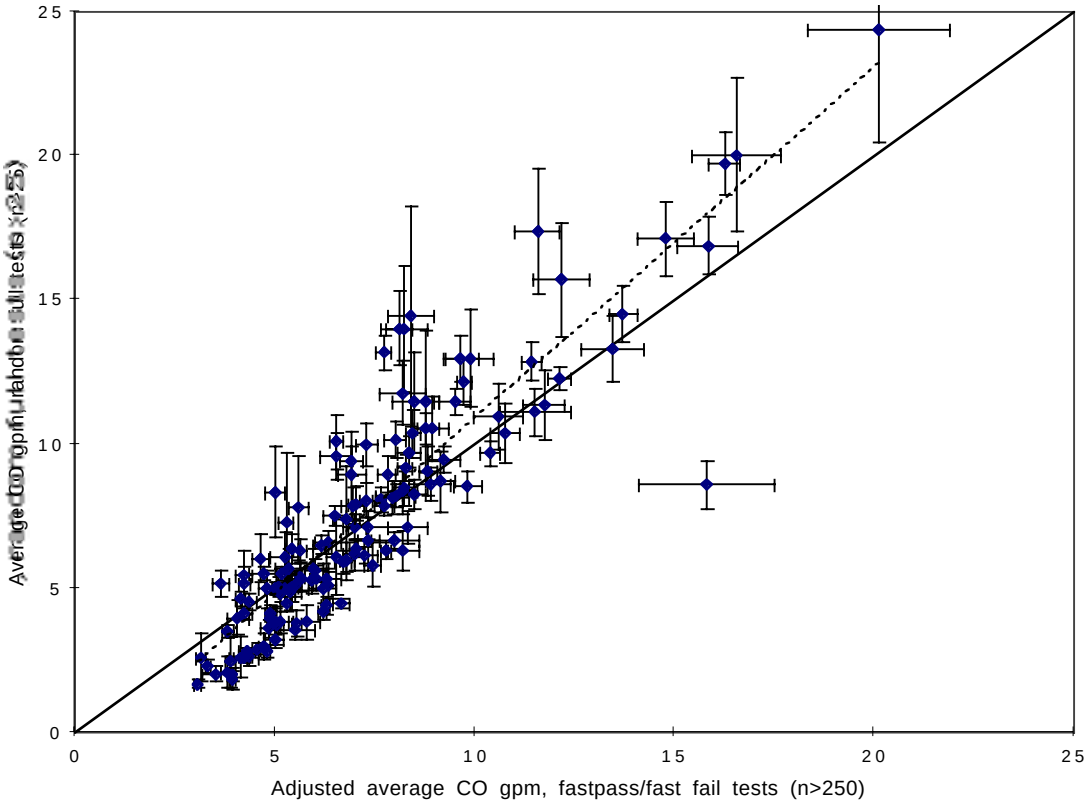


Figure 4. Average CO by Model, Fast Pass/Fail vs. Full Tests

Colorado MY90-93 with over 25 full IM240 test (July 1996 -- June 1997)



Average IM240 Emissions by Model in Three States

Figures 5 through 7 compare the average emissions of NOx, HC, and CO for 47 model year 1991 car models with at least 100 individual vehicles tested in each state. Each point represents a particular vehicle model, with average emissions from Arizona plotted on the x-axis and average emissions from Colorado and Wisconsin plotted on the y-axis. Average emissions by model in Colorado are designated by closed diamonds, whereas average emissions by model in Wisconsin are shown with open triangles. In each figure the solid line shows correlation with the Arizona data, while the dashed lines indicate the regression lines for the Colorado and Wisconsin data.

Figure 5 shows excellent agreement in average NOx by model among the three programs. NOx emissions are slightly higher in Arizona than in Colorado and Wisconsin. NOx emissions by model range from about 0.5 gpm to over 1.5 gpm, a factor of 3 difference between the lowest- and highest-emitting models. Two models are the highest emitters in each state, while 3 models are the lowest emitters in each state.

Figure 6 shows good agreement among the three states in terms of average HC by model. HC emissions are consistently lower in Wisconsin than in Arizona and Colorado. HC emissions by model range from about 0.2 gpm to over 0.8 gpm, a factor of 4 difference between the lowest- and highest-emitting models. Four models have consistently high emissions in all three states, while 6 models have consistently low emissions in all three states.

The two models with the highest emissions in Colorado, the Chrysler 2.2 liter and the Ford 5.0 liter, have relatively low emissions in Arizona and Wisconsin; these points are circled in the figure. One extreme emitter in Colorado, with 23 gpm HC, causes the average emissions for the Ford model to increase dramatically; removing this single vehicle reduces the average for that model to 0.77 gpm.

However, examination of the emissions distributions of these models also indicates that the difference in their average emissions among the states is due to generally higher emissions from many individual vehicles. **Figure 6a** compares the cumulative vehicle distributions for HC emissions from the Chrysler 2.2 liter model in the three states. The y-axis shows the cumulative fraction of vehicles with emissions above a given level on the x-axis; for example, about 8% of the vehicles in Colorado have HC emissions greater than 2.5 gpm, while less than 3% of the vehicles in Arizona have HC emissions greater than 2.5 gpm. The points noted indicate individual vehicles with high emissions. Even for the cleaner vehicles, the Chrysler 2.2 liter vehicles in Colorado have higher emissions than those in the other states; for example, 60% of the Colorado vehicles have HC greater than 0.5 gpm, while only 20% of the Wisconsin vehicles have HC above 0.5 gpm. Also, the dirtiest 1% of vehicles in Colorado (4 cars) have HC emissions nearly twice that of the dirtiest 1% of vehicles in Wisconsin (8 cars) and Arizona (4 cars).

Figure 6b compares the Colorado HC emission vehicle distributions of the two outlier models with those of a model that has consistently high HC emissions in each state

(Saturn SL/SC MFI) and a model that has consistently average emissions in each state (Nissan Sentra). The figure illustrates that in a rank comparison vehicle by vehicle, every Nissan car has lower emissions than every Saturn. Consequently, the high average emissions of the Saturn model are a result of consistently high emissions across all Saturns, rather than a few individual vehicles with very high emissions. The two outlier models may exist either as a result of sensitivities in these particular models to differences in the state I/M programs, or due to other differences between the states that affect emissions. For example, perhaps the emissions controls of these models are

Figure 5. Average NOx by Car Model in Three States

MY91 Passenger Cars with at least 100 IM240 tests (July 1996 -- June 1997)

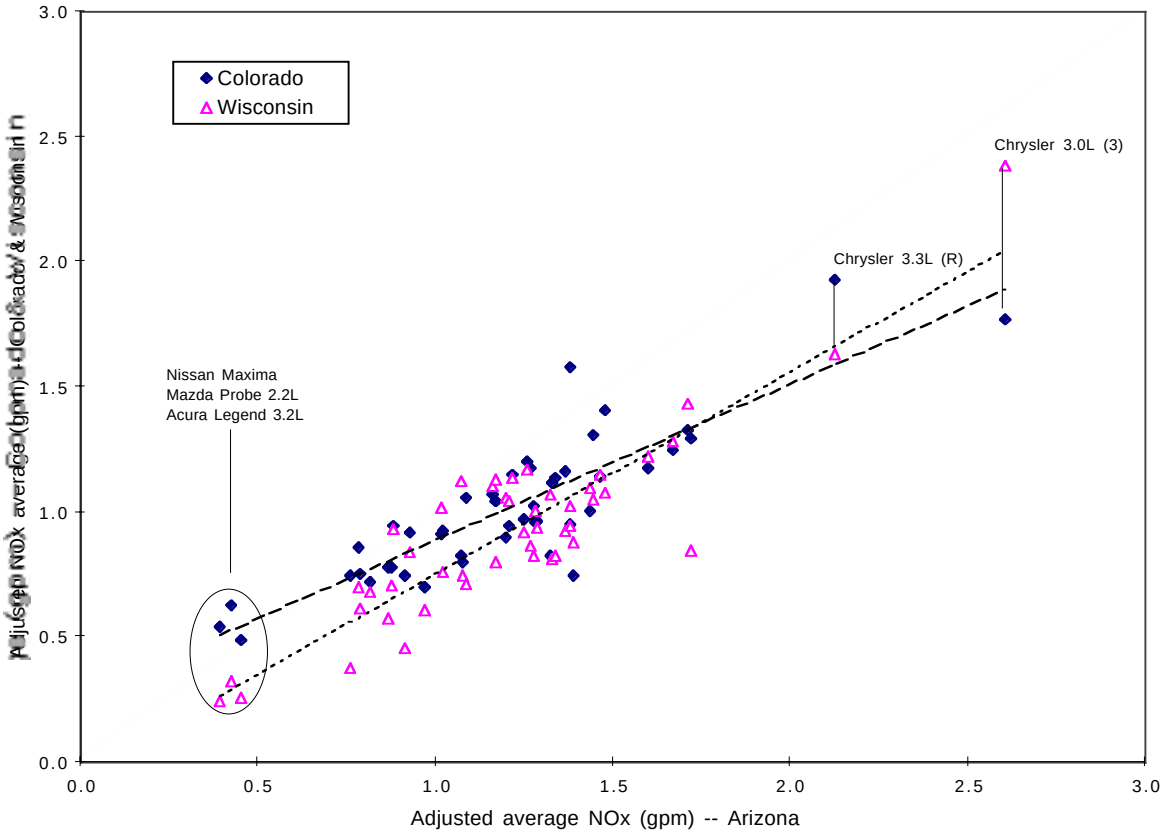


Figure 6. Average HC by Car Model in Three States

MY91 passenger Cars with at least 100 IM240 tests (July 1996 -- June 1997)

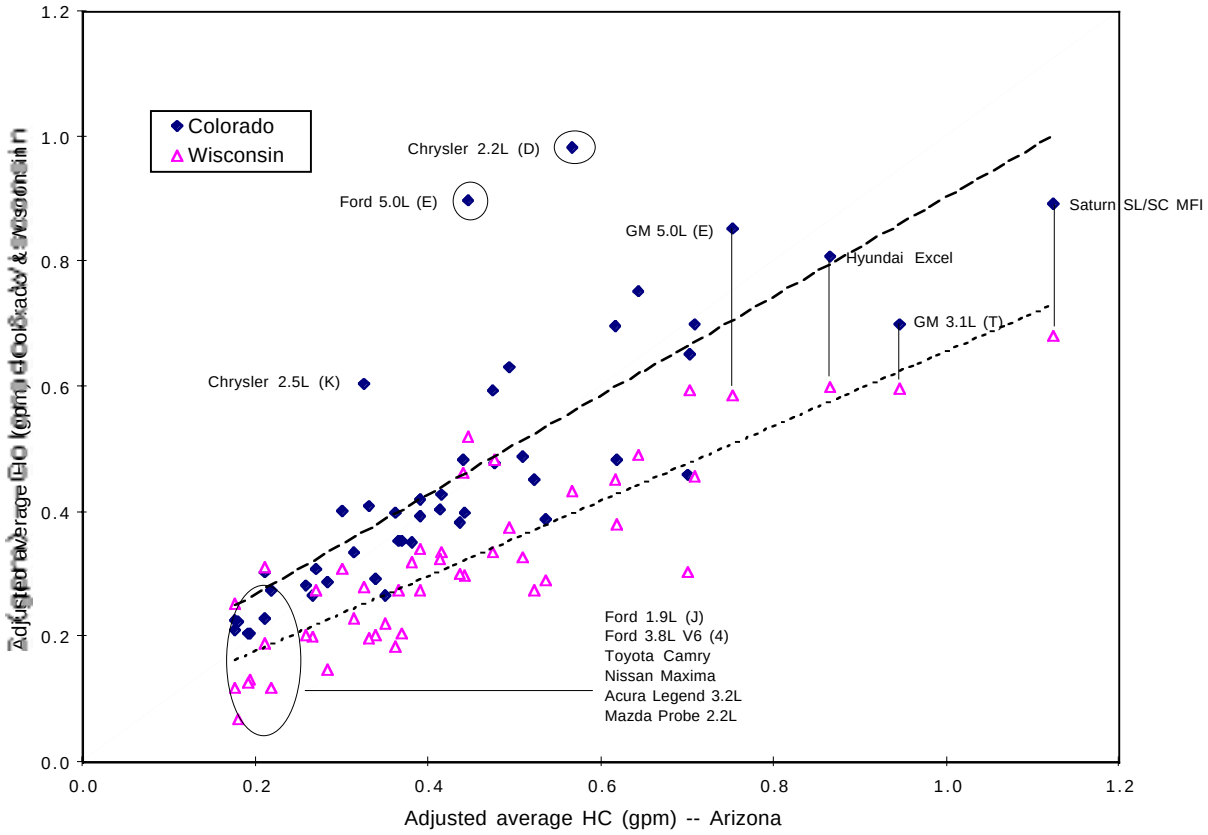


Figure 6a. Cumulative Vehicle Distribution for HC by State

MY 1991 Chrysler 2.2L (D) (July 1996 --June 1997)

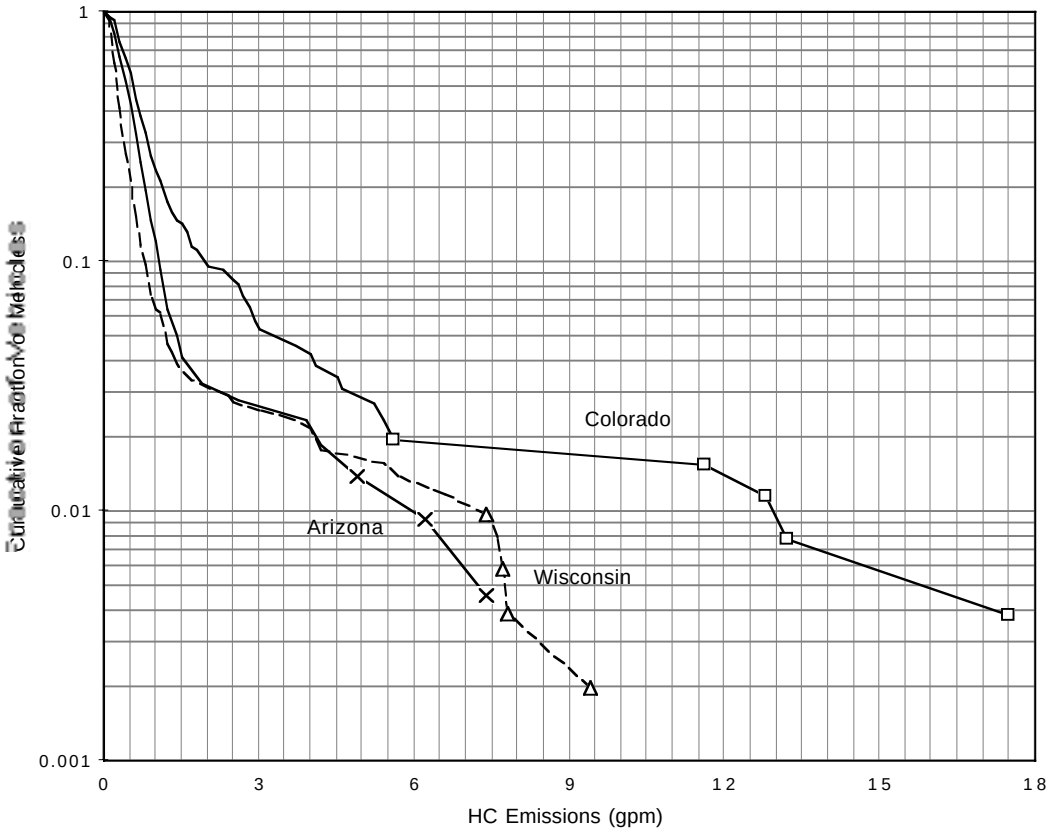
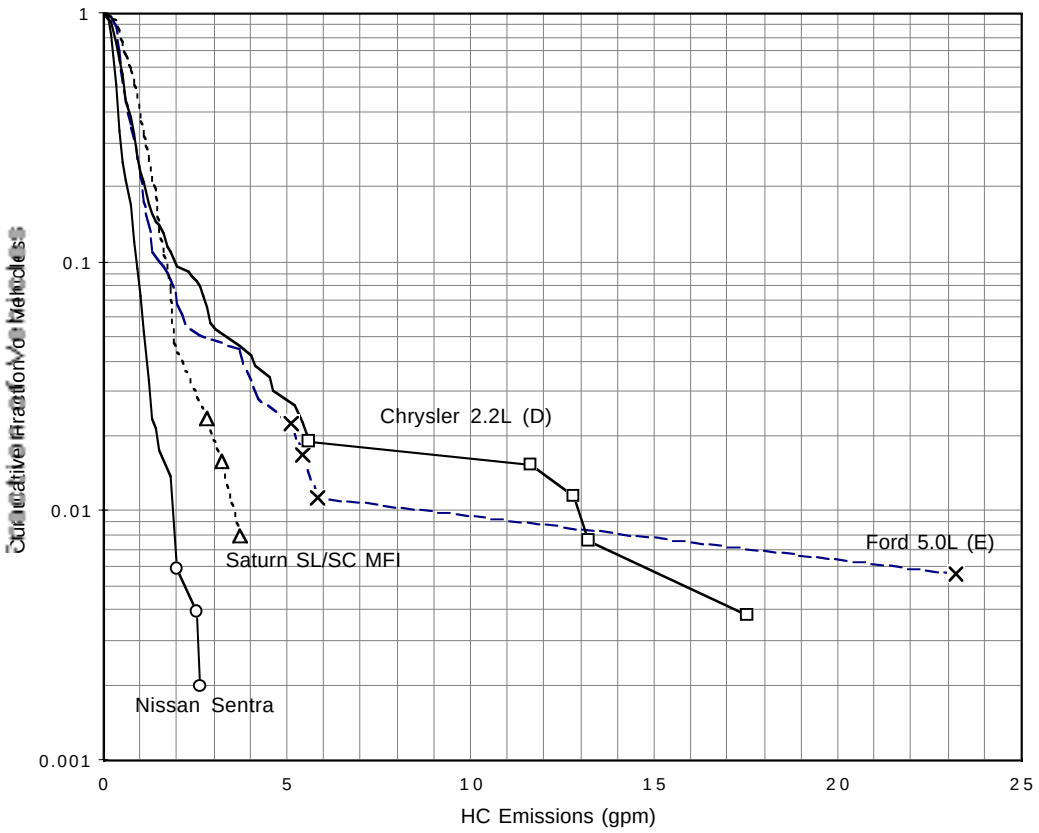


Figure 6b. Cumulative Vehicle Distribution for HC in Colorado

4 MY 1991 Passenger Cars (July 1996 -- June 1997)



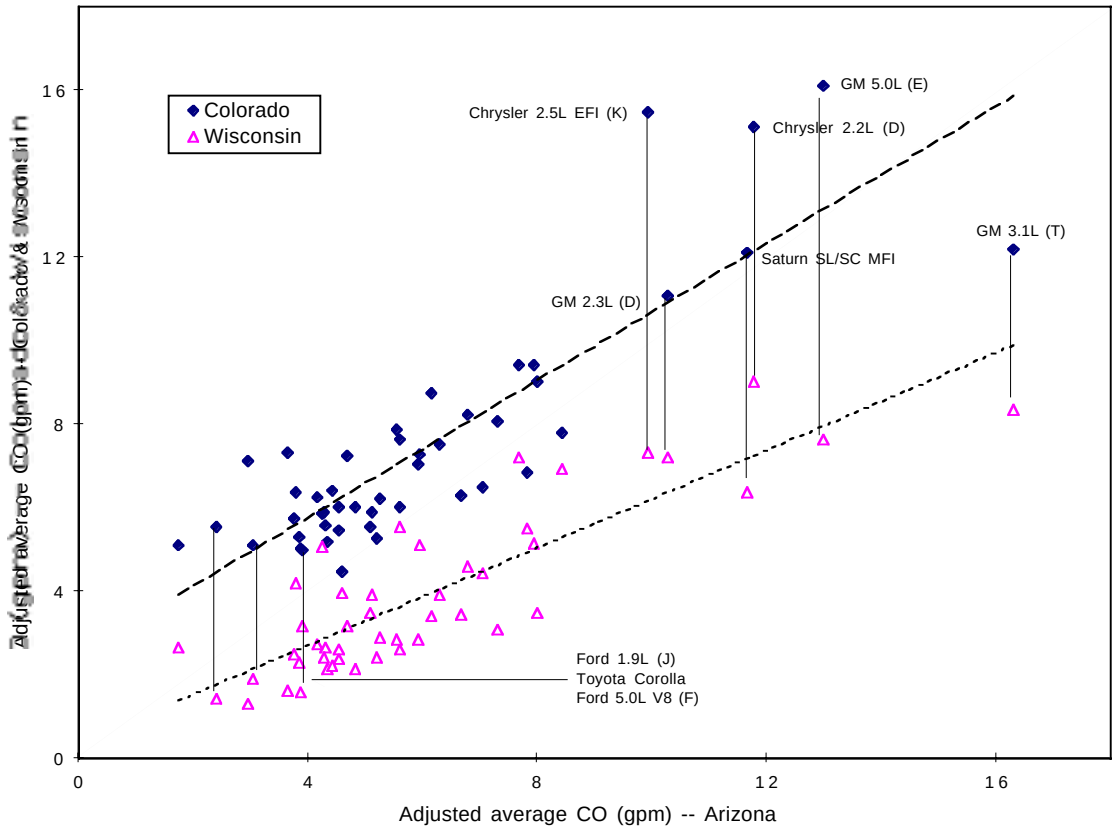
more sensitive to high altitude and/or high load driving, and therefore have higher emissions in Colorado than in Arizona or Wisconsin.

Figure 7 shows that average CO emissions for any given model tend to be substantially lower in Wisconsin, and substantially higher in Colorado, than in Arizona. Even so, there is good agreement among the three states. CO emissions by model vary by a factor of 3 in Colorado, to a factor of 7 in Wisconsin. Six models have consistently high emissions in all three states, while 3 models have consistently low emissions in all three states.

One possible explanation of the high Colorado, and low Wisconsin, CO emissions may be the different test cycles used in each state. Virtually all of the 1991 models were tested in 1996 in Wisconsin, while most of these models were tested in 1997 in Colorado; therefore, the Colorado vehicles are 6 months older on average than the Wisconsin vehicles. To evaluate this potential bias, we compared average emissions by model from vehicles tested between June 1996 and December 1996 only, and found that the Colorado CO emissions were reduced only slightly. There are two other factors that could account for the consistently higher emissions in Colorado: other differences in the I/M testing conditions, practices, or cutpoints used in each state, or differences in driving patterns, maintenance practices, and/or fuel composition in the three states that result in actual differences in in-use emissions.

Figure 7. Average CO by Model in Three States

MY91 Passenger Cars with at least 100 IM240 tests (July 1996 -- June 1997)



Summary

A comparison of in-use emissions data from three state IM240 programs indicates that average emissions by vehicle model are quite consistent across state programs. Several models are consistently among the cleanest, and the dirtiest, in each of the three states. Although the agreement is best for NOx, the comparisons for HC and CO are quite good. The two models with the highest HC emissions in Colorado have relatively low HC emissions in Arizona and Wisconsin. The inconsistent results for these particular models may be due to their sensitivity to I/M program differences, or to other factors that can affect in-use emissions.